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Abstract

This article is about the new universal architecture which allows electronic devices of different functionalities and manufacturers, as well as on-line services, to seamlessly interoperate with each other in the global scope of the Internet.

The main idea is that electronic devices and on-line services all over the world can join together by means of the Internet and form so called virtual communities. Within the bounds of these communities all the members can seamlessly discover each other by many different search criteria, establish dynamic cooperation sessions, control each other and monitor internal state within the bounds of established dynamic cooperation.

In order to organize virtual communities and provide interaction of their members the mathematical model of random metrized graph with small world properties is used and also an interaction protocol stack is proposed.

Key words: pervasive computing, cognitive networks, internet architecture, artificial intelligence, communication protocols, device discovery.

1 INTRODUCTION

In this article the new universal architecture is proposed which allows integration of electronic devices of different functionalities and manufacturers, as well as on-line services into virtual communities in a global scale of the Internet. This new architecture allows all the members of virtual communities to seamlessly discover each other by many different search criteria, establish dynamic cooperation sessions, control and monitor internal state of each other regardless of actual geographical location and physical network segment.

This article is organized as follows: in the section 2 a brief overview of publications in similar fields of research and development is provided. These publications form the basis of our research and development efforts.

In the section 3 we give a general overview of the offered architecture and briefly describe the main stages of electronic device cooperation.

In the section 4 we describe the so called functional entity cyber-passport. Cyber-passport is a detailed meta-description of any electronic device or on-line service and serves as a unique identity of this device throughout the so called global virtual communities of functional entities.

The section 5 of the article is dedicated to global virtual communities. Here we describe different types of communities, their internal structure and the most important properties of random metrized graph

mathematical model which forms the basis of global virtual communities' architecture.

In the sections 6–10 the main stages of electronic device cooperation in virtual communities are presented. Here we describe how an electronic device or on-line service is attached to a community, how it can discover another devices or services (called partners) in this community, how it can establish dynamic cooperation session with discovered partners, how partners can monitor internal state and control each other, and how dynamic cooperation session is terminated.

In the section 11 we discuss how devices and services can automatically coordinate each other in order to achieve common goals during dynamic cooperation.

2 RELATED WORK

During the development of the new architecture our efforts were based on many related works. Here we describe some of the most important ones.

In [1] and [2] some very important current trends in the Internet architecture and the so called Digital Home are discussed, as well as revolutionary changes in Internet services, for example, appearance of multimedia services like Voice over IP, Internet TV and Radio, Video and Audio on Demand as well as appearance of different automatic web services working without direct human intervention (so called machine-to-machine services). All of these trends form the stimulus for us to create a new universal architecture for dynamic cooperation of devices and services in the global scope.

There are some current efforts in the industry to create similar unified technology. An example of such a technology could be the Universal Plug and Play – UPnP [3]. But this technology has very strict limitation – it works well within the bounds of a physical network segment such as a home LAN in the Digital Home, but it couldn't be scaled globally over the whole Internet.

At the present time the research and development community has a significant interest in the principles and protocols of device and service discovery in networks. Examples of such protocols could be found in [4] and [5].

In publications [6] and [15] some ideas concerning meta-description of real-world things are discussed and language notations to express such meta-descriptions are proposed. These ideas form the basis of cyber-passports for devices and services in our architecture.

An XML language, which is described in [7] is actively used in the offered architecture as well as DOM-model [8].

Our ideas on creating internal structure of global virtual communities were grown up from publications [9] – [11], [15].

To establish and control dynamic cooperation sessions between devices in our architecture the Session Initiation Protocol (SIP) is used. It is described in [12].

A very interesting and deep research in the field of collective automata behavior was conducted by Victor Varshavsky [13], [14]. We based on his results in our work under the new architecture.

3 GENERAL OVERVIEW OF ARCHITECTURE

First of all it has to be noted that from the point of view of our architecture there are no any differences between electronic devices and on-line services, both of them can interoperate using the same mechanisms which will be discussed below.

Taking into account all fore mentioned, terms “electronic device” and “on-line service” are denoted using common term “functional entity”.

The following architecture is based on the model of the step-by-step interoperation of functional entities. Let’s take a brief overview of these stages:

Stage 1 – Cyber Passport Issuing. At the first stage each functional entity acquires its virtual representation which is meta-description containing information about all of its important aspects concerning external and internal structure, behavior, current internal state and so on. This meta-description is called Functional Entity Cyber Passport.

Stage 2 - Virtual Community Attachment. According to the following architecture all the functional entities are participating in so called Virtual Communities – VCs. Any functional entity whether it is an electronic device or on-line service, which has a cyber-passport can join one or several virtual communities.

Stage 3 - Partner Entity Discovery. When the functional entity becomes a member of some virtual community it gains the possibility to discover some partners within this community in order to carry out some task by a joint effort.

Stage 4 – Dynamic Cooperation Establishment. When the functional entity discovers one or several partners in the virtual community it can establish a so called dynamic cooperation session with them in a unified manner.

Stage 5 – Partner Entity Control and Notification. Once the dynamic cooperation session is established, entities which are partners already can exchange control messages and notifications of different changes in their internal state.

Stage 6 – Partners Orchestration. In order to carry out some tasks by a joint effort in the completely automatic mode, i.e. without human intervention, functional entities proceed with mutual coordination

activity and guide each other to the solving of assigned task. The principle of such a mutual coordination of partners we called «Partners Orchestration».

Stage 7 – Dynamic Cooperation Termination. When the assigned task will be completed by joint efforts of partners, functional entities terminate the dynamic cooperation session. Also the session can be terminated at any point by means of an external command.

Let’s take a look at all of the fore mentioned stages of functional entities interoperation in more details.

4 CYBER PASSPORT ISSUING

As it has been noticed earlier, at the first stage a detailed meta-description is created for every single functional entity. This meta-description contains information about all of the aspects of internal and external structure and behavior of the given functional entity.

For example, if such an entity was a multimedia device such as a TV set then its meta-description would contain unique (in the global scope of the whole Internet) id, device type info according to some universal classification, information about model, manufacturer, current owner and actual geographical location as well as description of command interface, internal state model, methods of physical device control (e.g. via IP-network, 10-feet IR interface, Bluetooth or by other means), description of multimedia capabilities, information about all of the external connectors, jacks and sockets with their current internal state and so on.

To declare meta-descriptions in our architecture we developed a special XML dialect [7] which is called FEPDL – Functional Entity Passport Description Language. All meta-descriptions declared using FEPDL have a tree-like hierarchical internal structure and can be modeled using standard Document Object Model – DOM [8].

Given meta-descriptions will be called «cyber-passports». And functional entities for which these passports are created here and forth will be called «cyber-passport owners».

Cyber-passports of functional entities can be physically stored either inside their owners or outside – on the specialized hosting servers in the Internet [10], [15]. In the former case the representation of the cyber-passport to the external world is provided by the owner entity, while in the latter case this entity should have a possibility to access its cyber-passport via corresponding hosting server.

Cyber-passports of functional entities are used during all of the stages of interoperation in our architecture.

5 VIRTUAL COMMUNITIES OF FUNCTIONAL ENTITIES

According to the concept underlying the described architecture, there will be a multitude of interconnected virtual networks overlaying the entire Internet, the so called Internet overlay networks, similarly to the manner the Web now exists in over the Internet. All this overlay networks in turn will consist of interconnected functional entities represented by electronic devices and on-line services of extremely diverse functionalities (see Fig. 1). Such overlay networks are called Virtual Communities of Functional Entities – VCoFE.

functional entities in the virtual community. As the ribs of the random graph (random VCoFE-graph) there are so called Logical Friendship Links – LFLs formed between the FERUs of individual functional entities. On all the set of nodes of the overlay network there is a defined metric determining the degree of informational closeness of each specific pair of nodes [9] – [11].

A Functional Entity Representation Unit is a part of a functional entity – an electronic device or on-line service. By its internal structure a FERU is an active informational-functional complex consisting of a

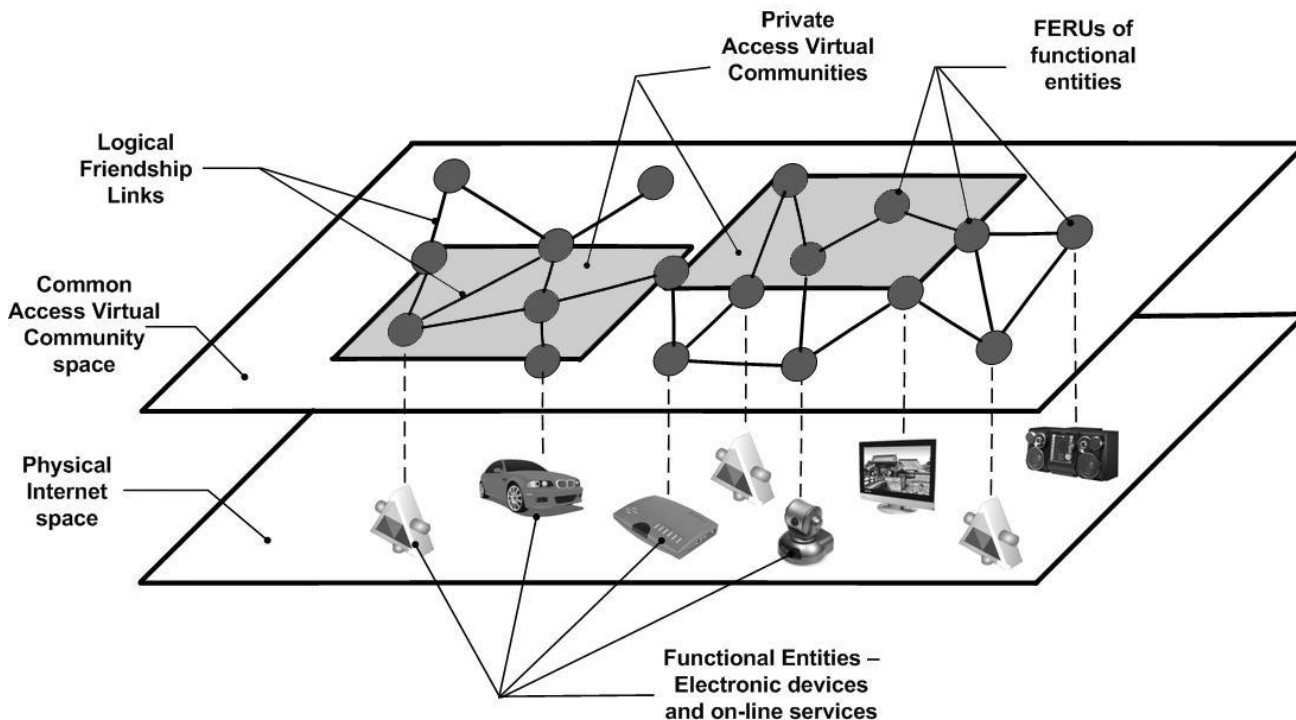


Figure 1. Virtual communities of functional entities structure

Functional entities having cyber-passports form one huge overlay network covering all the space of the Internet. That network is called the Common Access Virtual Community (CAVC) – the virtual community of common access. We can think of a CAVC as an analog of the modern Web. It's an open network and on default all the functional entities have a free access to it.

Apart from the community of common access to the Internet, also there will be a plenty of private communities that we called Private Access Virtual Communities – PAVC. A same functional entity can simultaneously participate in several different virtual communities, for instance in a CAVC and one or several PAVCs. For certain reasons, some functional entities may be excluded from the CAVC and participate in private communities only.

The Internet overlay network of a virtual community is mathematically modeled by a metrized random graph. In the nodes of that graph are located so called Functional Entity Representation Units – FERUs which are responsible for completely representing

functional entity's cyber-passport, the listing of actual logical links with other "friendly" FERUs in that virtual community, as well as an active module providing all the necessary logic for the FERU's operation inside the virtual community's overlay network.

Logical Friendship Links formed between individual FERUs in the virtual community are mutual references of FERUs to each other together with some meta-information associated with those references. The mentioned meta-information contains the values of metric distance between corresponding FERUs participating in the given LFL.

To unite FERUs into a connected network of community, a special VCoFE Assembling Algorithm [9] – [11] is used. It's based on computing metric distances between individual pairs of FERUs, It's created in a way allowing to ensure a number of the most significant properties of the resulting graph. One of these properties is that the resulting VCoFE-graph is fully connected, i.e. all its vertices are reachable for each other regardless of their number. Besides, that graph has the small-world properties what means that

the average value of minimal path length between any two nodes in this graph grows logarithmically with the total number of its nodes. It allows creating a very efficient search algorithm that can rapidly find needed functional entities even in enormous multimillion virtual communities.

6 VIRTUAL COMMUNITY ATTACHMENT

When a functional entity acquires its cyber-passport, it has the possibility to join one or several virtual communities by means of its FERU.

As it was said above the joining of functional entity into VCoFE is, in fact, means integration of its FERU into corresponding overlay network. The procedure of joining functional entity into virtual community is initiated through one of its members which, in this case, play the role of the special entry point into given virtual community. A FERU of any functional entity that is a member of a virtual community could be an entry point into this community.

To successfully join some VCoFE, a functional entity needs to know access parameters for that virtual community such as id of this community, references to some entry points, security parameters and so on. All this information in tote is called Virtual Community Access Configuration.

In has to be noticed that all the operations during the attachment of a functional entity into virtual community are provided by means of interaction of the entity's FERU with similar FERUs of other entities-members of the given community. These FERUs are interacting by a specially developed protocol.

7 PARTNER ENTITY DISCOVERY

Once the functional entity becomes a member of a certain virtual community, it immediately receives the opportunity to search for other functional entities which we call partners within that community in order to establish a dynamic cooperation with them for a jointly completing some tasks.

A partner for our functional entity can be any other entity satisfying certain criteria necessary for a fruitful joint action within the dynamic cooperation session.

The above-mentioned criteria are determined by the functional entity in each specific case individually, depending on a set of factors. The totality of all the factors influencing choosing partners in each concrete case is called the context of the search situation the given functional entity is being in. This context is described by means of a specially developed data structure which was called a Partner Discovery Context – PDC. The functional entity possesses a special mechanism allowing constantly tracing the search situation context and updating the PDC when needed.

In case of an emerging task requiring a partner for its solution, the functional entity utilizes the task's parameters and the PDC's data to formulate the criteria for searching a partner in the virtual community. After that, based on the search criteria, a so called search mask is formed.

A search mask is an XML document formed on the basis of the same dialect FEPDL (Functional Entity Passport Description Language) the cyber-passports of functional entities are specified in. The internal structure of a search mask is similar to the internal structure of a cyber-passport and the values of the search parameters are accommodated in the corresponding nodes in the mask's structure.

Formed in the accordance with the search situation context, the mask is then used by the FERU for searching a partner in the virtual community. The search is conducted by means of a consecutive traversal of some set of nodes (Functional Entity Representation Units) in the overlay network of the virtual community. For each considered node, a metric between its cyber-passport and the search mask is computed. If the value of the metric distance is equal or smaller than the level given by the search context than the considered FERU is declared to be the search's result. Otherwise the unit is considered insufficiently relevant to the search query and is not included in the list of search results.

Once the search procedure is completed, the results of the search are processed and from them the cyber-passports of one or several of the most appropriated partners are chosen. At this point the search stage is finished.

8 DYNAMIC COOPERATION ESTABLISHMENT

After the functional entity obtains, as a search result, one or several cyber-passports of potential entity-partners, it conducts an additional analysis of the data contained in the found cyber-passports concerning the correspondence of all the relevant parameters to the given requirements of the search context. As a result of the analysis, the most appropriate candidate for a partner is chosen and the functional entity receives a reference to it from its cyber-passport and initiates the process of establishing a dynamic cooperation session with that candidate.

All the process of establishing and controlling dynamic cooperation sessions in the given architecture is based on the standard Session Initiation Protocol (SIP) [12] and the Dynamic Cooperation Control Protocol (DCCP) developed by us. The initiation of a session is carried out by means of transferring a SIP-message to the entity-candidate with a DCCP-message specifying the forthcoming dynamic cooperation parameters inserted in the SIP-message's body.

In each specific case those conditions may strongly differ because they essentially depend on the type and parameters of the task solved within the given dynamic cooperation session. That's why, as an example, the above mentioned conditions may include a

reference to the cyber-passport of the entity that is the initiator of the cooperation, a set of control commands which are to be supported by the partner for successfully jointly solving the assigned task, the list of internal state parameters of the partner which are supposed to be accessible remotely for the purpose of monitoring, the formats and protocols of data exchange the partner should support, the QoS parameters needed for a qualitative data exchange during completing the task, the security parameters which must be ensured for all the session, the supposed duration and cost of the session etc.

After receiving the message, the functional entity-candidate analyses the offered cooperation parameters and makes a decision whether to participate or not in the given dynamic cooperation. If the decision is positive then the entity candidate sends to the initiator an answer in the form of SIP-message whose body a DCCP-message is inserted in. That DCCP-message specifies all the parameters accepted by the candidate within that session.

If the initiator agrees on those parameters then the dynamic cooperation session is considered to be established.

9 PARTNER ENTITY CONTROL AND NOTIFICATION

According to the suggested architecture, the external interfaces of each functional entity are modeled by a certain set of meta-commands and meta-events. The totality of meta-commands is an abstraction of the functional entity control interface and the totality of meta-events models its internal state what provides an opportunity for remote monitoring.

In the cyber-passports of all the functional entities the lists of supported meta-commands and meta-events are mandatorily declared. Then those lists are used by potential partners for searching in the virtual community, establishing dynamic cooperation sessions, controlling, and remotely monitoring the given functional entity.

The meta-commands are carriers of semantics and the essentials of the actions of certain functional entities, for instance, to switch on/off power, to switch to one of the supported operational modes, to start some predefined process (such as the playback of a media content unit, transferring some data set, switching on an engine, a heating device, a refrigerator or a fan), to stop some predefined process etc. I. e. a meta-command has the meaning of actions which are the most common for the majority of functional entities (for instance, the above-mentioned meta-commands can be found virtually in all the electronic devices in that or another form). However it's worth noticing that, after receiving a same command, different entities execute it in their own manners, depending on the entity functionality and context. The same concerns meta-events.

To successfully collaborate within a dynamic cooperation, arbitrary entities should be compatible with each other on the level of meta-commands and

meta-events. To ensure such compatibility, all the above-mentioned search mechanisms and the agreements on the dynamic cooperation are used.

For the purpose of functional entities control within a cooperation session the specially developed Remote Peer Control Protocol – RPCP is used. It utilizes meta-commands supported by entities for their control.

For monitoring entities-partners within a dynamic cooperation session the Remote Peer Notification Protocol – RPNP is applied. According to this protocol, a functional entity is subscribing to a certain meta-events supported by partners and then receives notifications in case if subscribed event changes its state. It allows carrying out the monitoring of all the partners within dynamic cooperation session.

To exchange messages of RPCP and RPNP protocols between functional entities, the SIP protocol is used. And the message exchange is carried out by means of SIP-messages of the type MESSAGE [12] whose body corresponding RPCP and RPNP messages are inserted in. Hence in that architecture the SIP protocol has a double functionality: on one hand, it is a tool for establishing and controlling cooperation sessions, and on the other hand it is a transport for transferring the messages of controlling protocols within cooperation sessions.

10 DYNAMIC COOPERATION TERMINATION

As soon as the assigned task is completed by joint efforts of entities-partners, the dynamic cooperation session is terminated. Also a session can be terminated as a result of some external or internal events, for example, by user initiative.

Termination of a dynamic cooperation session is initiated by one of functional entities involved in this session. Entity-initiator sends a SIP-message of type BYE to its partner, and receives an answer SIP-message of type OK. As a result of this transaction dynamic cooperation session is terminating.

11 PARTNER ORCHESTRATION

Carrying out any task by joint efforts of several entity-partners requires a mutual coordination of their activities. The RPCP and RPNP protocols for control and monitoring of functional entities are just only like «working horses». But for successful jointly solving of assigned tasks there is a need for a «horseman» who knows when and how to pull the reins, who can reason about the results of his actions which he perceives by means of a remote monitoring. Such a horseman could be a human who controls an aggregated system of several dynamically cooperating functional entities. But if the human user is not participating, these cooperating functional entities should be able to coordinate each other in the automatic manner.

A very deep research of the problem of automatic coordination behavior of distributed systems consisting of many independent functional entities was carried out by Professor Victor Varshavsky and is presented in [13], [14].

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